Heliyon 9 (2023) e17288

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

The impact of future climate on orange-fleshed sweet potato production in arid areas of Northern Ethiopia. A case study in Afar region

Gloria Peace Lamaro [a,*], Yemane Tsehaye [b], Atkilt Girma [a,c], Damasco Rubangakene [a]

[a] *Institute of Climate and Society, Mekelle University, P. O. Box 231, Mekelle, Ethiopia*
[b] *College of Dryland Agriculture and Natural Resources, Department of Dryland Crops and Horticultural Sciences. Mekelle University, P. O. Box 231, Mekelle, Ethiopia*
[c] *College of Dryland Agriculture and Natural Resources, Department of Land Resources Management and Environmental Protection (LaRMEP). Mekelle University, P. O. Box 231, Mekelle, Ethiopia*

ARTICLE INFO

Keywords:
Time segment
Representative concentration pathways
Climate projection
Sweet potato storage root yield simulation
Aqua crop
Climate change
Afar region

ABSTRACT

Sweet potato is in its introductory phase as a food-based approach to alleviate malnutrition in the Afar region, where, due to climate change, agricultural drought impedes crop production. This study assesses the impact of climate change on orange-fleshed sweet potato (OFSP) fresh storage root yield production over the Afar region using the Aqua Crop model. This model was fed with daily rainfall and minimum and maximum temperature datasets, for the baseline climate (1980–2009) as well as future (2010–2099) climate projections under two representative concentration pathways: RCP 4.5 and RCP 8.5. These datasets were statistically downscaled from twenty (20) general circulation models that are used in the Coupled Model Intercomparison Project Phase 5 (CMIP5). The impact of climate change on sweet potatoes was assessed by comparing the change in average sweet potato yields in the baseline climate condition against the average of simulated sweet potato yields in the Near-term (NT) (2010–2039), Mid-term (MT) (2040–2069), and End-term (ET) (2070–2099) under RCP 8.5 and RCP 4.5. Simulation shows increased future storage root yield production for NT (3.23%), MT (3.90%), and ET (7.25%) under RCP 4.5 and MT (5.88%) and NT (6.71%) from the observed yield data (32.0 t/ha) except for Near-term (−9.59%) under RCP 8.5. Similarly, projected climate shows increase in temperature Tmax (0.93–4.10 °C), Tmin (0.88–4.54 °C) and precipitation (28.9–37.8%) under both RCPs which will favor sweet potato yield production increase in near-term, mid-term reaching climax in end-term. Simulation with planting dates shows that normal planting date (July 01), gives better yields than early (April 22) or late planting (01 August). This finding may perhaps be used as preliminary data in adoption and upscaling of orange-fleshed sweet potato in Afar region.

1. Introduction

The biological cycle of crop production comprises of versatile interactions among the soil, atmosphere and the crop plant itself: change in any of the elements of weather or soil may give rise to desirable or unattractive consequences on the crop plant under

---

[*] Corresponding authorInstitute of Climate and Society, Mekelle University, P. O. Box 231, Mekelle, Ethiopia.
E-mail address: peaceglam@gmail.com (Gloria Peace Lamaro).

https://doi.org/10.1016/j.heliyon.2023.e17288
Received 17 December 2022; Received in revised form 6 June 2023; Accepted 13 June 2023
Available online 21 June 2023
2405-8440/© 2023 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

investigation [1]. Changes in global climate have corresponding significant effects on crop yields, nutrient content and productivity [2]. Global atmospheric temperature analysis shows a rise in temperature from 2.5 °C to 4.8 °C by the end of the 21st century (2100) [3, 4]. It's well established that both atmospheric and soil temperature poses a great influence positively or negatively on sweet potato crop plants at all phases of growth and development in farmers field conditions or natural environment [5–7]. Low temperature inhibits nutrient uptake, photosynthesis, storage root initiations, growth and development [5,6,8]. Meanwhile, higher temperature above 25 °C encourages storage root enlargement [9]. Temperature also influences migration, redistribution and multiplication of sweetpotato pests and disease for instance, sweet potato virus diseases (SPVD) were more common in hot environment with temperature above 30 °C [10,11], while migration and redistribution of pest and pathogens was witnessed at higher altitudes with a cool environment temperature [12].

The anthropogenic emission of carbon dioxide (CO_2) is expected to rise above 700 ppm by the end of the 21st century; this increase in carbon dioxide accumulation would favor productivity of sweet potato and potato [13]. In sweet potato and other C_3 plants, elevated Carbon dioxide concentration enhanced escalated water use efficiency and photosynthesis which promotes growth and bulking of storage roots [14,15]. [16] (2018) reported increased sweet potato storage root dry weight of up to 40.9% when variety CX-I was grown in higher carbon dioxide concentration of ambient + 200 μmol mol-1 compared to those under ambient (395 μmol mol-1) CO_2 concentration. Similarly [15], (1996) in a two-planting season experimental study, observed an increase in storage root dry weight of 44% and 75% with a 665 μmol mol-1. Other authors reported increased biomass yield between 33 and 40% due to elevated carbon dioxide concentration [17,18].

Change in rainfall pattern combined with rise in temperature may alter the suitability of many crops land forcing them to become marginal due to increase evapotranspiration [19]. Transformation of irrigation schemes to augment water use efficiency supports climate risks management and adaptation. Increased water productivity coupled with good agronomic practices will lead to sustainable high crop yield production [19].

Generally, understanding of the impact of climate change on crop production through agricultural experiments are very expensive and time consuming [1]. Therefore, systems analysis and simulations can be done to potentially lower the costs and time of considerable field experimentations required for testing any new crop cultivar(s) or new agronomic management systems using models. Crop simulation models have the ability to foretell the reactions of any given crop plant to weather variability by predicting the output [1]. According to Murthy [1], crop growth models can be used to predict crop performance in new places where the crop has not been grown before. It can also be used to predict a crop plant response to certain climatic, soil or management condition, as a tool for management and decision-making [20]. In Ethiopia, information regarding the future prospects of sweet potato production and the possible adaptation/mitigation strategies for sustainability are scarcely found. Sweet potato experimentation was not done before in Afar region until the year 2019 [11]. Study on future production possibilities of sweet potato in Afar region was not done yet. The fore knowledge on the yield response of sweet potato in the future will help to advice the farmers, policy makers, and investors in sweet potato on better response mitigation or adaptation strategies that will enhance optimum sweet potato yield production, supply and sustainability. The aim of this study was to simulate sweet potato root yield production under the current and future climate scenarios, and recommend adaptation strategies in the years when climate changes against good crop harvests.

2. Materials and methods

The study covers the areas of Aba'ala in Afar region. Aba'ala is found at an altitude of 1441 masl, a latitude and longitude 13° 34′19′N, 39° 94′17′E respectively. Aba'ala is categorized as belonging to the arid agro-climatic lowland with an average minimum and maximum temperature of 18.6 °C and 34.0 °C respectively. The arid agroclimatic zone has a length of growing period shorter than 60 days [21,22].

The input data set used in this study include sweet potato field experimental data of 5 years (2015–2019) sourced from Aba'ala, and Tigray Agricultural Research Institute (TARI) with some modifications [11,23–25]. These data are sweet potato planting date, date of flowering, date of maturity, storage root yield, biomass yield, rooting depth, canopy development, harvest index, data on tillage, planting, Cultivar, spacing, soil water requirement and sweet potato growth requirements.

Climate data for Aba'ala weather station in Afar region was collected from the Ethiopia National Meteorological Agency (ENMA). The data collected were on the weather elements daily observations for the past 30 years (1989–2019) for maximum and minimum temperature (Tmax and Tmin), relative humidity, wind speed, solar radiation and rainfall. This meteorological data collected from NMA had missing values therefore, statistically down scaling and bias-correction was done using a comprehensive daily weather data for Aba'ala station, Afar region obtained from Agricultural Model Intercomparison Project (AgMIP). The gap-filled dataset was prove checked using TAMET software. The impact of Carbon dioxide concentration on storage root yield was accessed by incorporating carbon dioxide concentration from the yearly atmospheric Carbon dioxide concentration – IPCC: RCP 4.5 (538 ppm) and RCP 8.5 (930 ppm) carbon dioxide file, and the default ambient atmospheric carbon dioxide concentration (380 ppm) for RCP 4.5, RCP 8.5 and baseline respectively.

Data on soil was taken from ISRIC soil map [26], FAO Aqua crop model [24], and soil sampled from Aba'ala in the year 2019. Soil samples were taken from point locations of the study area diagonally using a soil augur at a depth of 10–40 cm and were air-dried and submitted to the TARI soil laboratory for chemical and physical analysis. Other samples for physical analysis were taken using a labeled metallic core. Samples were analyzed using the procedures described by Von Reeuwijk [27] (1993) and [28] (1999) The result was later fed to Aqua Crop.

The study data was analyzed using FAO Aqua Crop model 6.0 versions [24] and free R-software [29]. R software [29] was used to project the future climate of Afar region using meteorological data from Coupled Model Intercomparison Phase 5 (CMIP5) and baseline meteorological data (1980–2009) for Aba'ala weather station in Afar region. From this, delta adjusted statistically downscaled climate data (temperature minimum, temperature maximum and precipitation) for three-time segments Near-term (2010–2039), Mid-term (2040–2069) and End-term (2070–2099), and two representative concentration pathways (RCP 8.5 and RCP 4.5), and twenty general circulation models (20 GCM) were generated using the "R" script "AgMIP_simple_delta. R″ following the guide for running AgMIP Climate Scenario Generation Tools with R in Windows [30]. The predicted future climate datasets for Aba'ala weather station, Afar region was then extracted in R software and climate model ensembles were created using pivot table function. Climate ensembles was done to seize uncertainties in prediction which may result from differences in model parametrizations and enhance estimation of certainty of results [31]. The ensembled future climate datasets for Near-term (2010–2039), Mid-term (2040–2069) and End-term (2070–2099) for each of the RCP 8.5 and RCP 4.5 were fed to the ETo calculator version 3.2 [32], where calculation of daily reference evapotranspiration (ETo) for the time segments under both RCPs was done. The ETo was then exported to the FAO aqua crop model. Both the ensembled meteorological data for different time segments and ETo data were then used to drive the FAO Aqua crop model.

FAO Aqua Crop model is a crop-water productivity model that simulates yield response to water of herbaceous crops and is particularly suited to address conditions where water is a key limiting factor in crop production. It imitates crop plant response to changes in carbon dioxide concentration levels, soil quality, management practices, climate and water use efficiency [24]. It uses meteorological data temperature maximum (Tmax), temperature minimum (Tmin), precipitation (rainfall), reference evapotranspiration (ETo), and Carbon dioxide CO_2 concentration. It also uses planting dates, the crop development requirements which includes the soil water requirements and the management factors for instance field management practices and irrigation [24], but in this study, rainfed cropping was used. The climate files used to power aqua crop came from the baseline (1980–2009), projected climate for Near-term (2010–2039), Mid-term (2040–2069) and End-term (2070–2099), and the measured climate data from NMA (1989–2019), The CO_2 data was obtained from the aqua crop inbuilt IPCC RCP 8.5 and RCP 4.5 CO_2 files.

The FAO Aqua Crop model was calibrated with sets of data shown in Table 1. These data were obtained from experiment record of orange-fleshed sweet potato Ininda cultivar produced in Afar region in the year 2019 with some modifications from FAO Aqua Crop manual for sweet potato, and other authors [11,23–25]. Aqua crop model validation was done using observed meteorological and yield data collected in 2015–2019 from NMA Ethiopia, Aba'ala, and TARI respectively. To quantify the disparity between the simulated data and the observed data, the normalized root mean squared error (nRMSE) was calculated using the procedures suggested by Loague and Green [33]:

$$nRMSE = \frac{100}{\sigma}\sqrt{\frac{\sum_{t=1}^{n}(P_t - O_t)^2}{n}} \tag{1}$$

Where; P = simulated value; O = observed value; σ = is the mean of the observed data; n = the number of the observations.

The methodical bias of the model was estimated by calculating the root mean deviation (RMD) using a formula given by Nash, and

Table 1

FAO Aqua crop calibration parameters.

Crop parameters	Values
TMin (°C)	8
TMax (°C)	38
Initial canopy cover (%)	0.42
Number of plants per hectare	55,556
Canopy growth coefficient (%/°C-day)	0.22230
Canopy cover 30 days after planting (%) - 30 DAP	60
Canopy cover 90 days after planting (%) - 90 DAP	100
Canopy cover 120 days after planting (%) - 120 DAP	90
Time to start senescence (degree days)	1340
Canopy decline coefficient (%/°C-day)	0.141
Growing cycle (degree days)	1930
Minimum effective rooting depth (Z min (m))	0.25 M
Maximum effective rooting depth (Z max (m))	1.5
Shape factor	2
Crop transpiration coefficient (Kcb)	1
Time from planting to maximum depth (degree days)	658
Reduction with age (%/day)	0.15
Soil water evaporation coefficient Ke (%/day)	1
Water productivity (WP (g m-2))	20
Reference harvest index (%)	90
Building up of HI (degree days)	997
Increase (%) of HI	5% HIMax 94
Depletion factor (for ET ~ 5 mm/day	0.65
Air temperature stress (°C-day)	8
Minimum growing degrees required (°C-day)	8

Adopted from Refs. [11,23–25].

Sutcliffe [34]:

$$RMD = \frac{100}{\sigma} \sum_{t=1}^{n} \frac{P_t - O_t}{n} \tag{2}$$

Where; RMD = root mean deviation: P = simulated value; O = observed value; σ = is the mean of the observed data: n = the number of the observations.

Model efficiency (ME) was calculated to determine the model performance efficiency relative to the observed mean using the formula derived by Nash, and Sutcliffe [34]:

$$ME = \frac{\sum_{t=1}^{n} (O_t - \sigma)^2 - \sum_{t=1}^{n} (P_t - O_t)^2}{\sum_{t=1}^{n} (O_t - \sigma)^2} \tag{3}$$

Where; ME = Model efficiency; P = simulated value; O = observed value; σ = is the mean of the observed data; n = the number of the observations. The more nearer the model efficiency is to 1 symbolizes great accuracy. The ME range from ∞ to 1. Linear regression was done between the observed and simulated data to appraise the model operations and correlation coefficient.

3. Results

3.1. *Appraisal of crop model using observed and simulated storage root yield data for period 2015–2019*

The aqua crop model evaluation in predicting yield response is presented in Table 2. Both the nRMSE and RMD were low. The study also observed high ME and relationship between the observed and simulated storage root yield.

3.2. *Relationship between the observed and projected climate data using two RCP and three time series*

The graphical illustration of relationships between the baseline and projected TMax, TMin and rainfall is presented in Fig. 1. Strong linear relationship was observed between baseline and projected climate data for TMax and Tmin of the same years. Meanwhile, weak relationship was recorded between the baseline and the predicted rainfall data.

3.3. *Projected temperature and rainfall of the study area*

The projected climate show rainfall increases from the baseline by 28.9% and 36.1% under RCP 4.5 near-term (NT) and Mid-term (MT) respectively. Rainfall increase was higher in NT and MT compared to End-term (ET) under same RCP. Under RCP 8.5, the simulated rainfall increased for all-time segments NT, MT and ET. Similarly, simulation of temperature showed increase in maximum temperature (TMax) and minimum temperature (TMin) for all the periods (NT, MT and ET) under both RCP 4.5 and RCP 8.5. The temperature increment was ≤ 1 °C for time series NT and >1 °C for time series MT and ET under both RCP 4.5 and 8.5 (Table 3).

3.4. *Fresh storage root yield simulation with current and future climate scenarios under two different RCPs 8.5 and 4.5*

Perfect relationship coefficient was recorded between the observed and predicted fresh sweet potato storage root yield (see Fig. 2). The relationship between currently observed and simulated fresh storage root yield quantities was comparatively good. The model estimated yield increase under both RCP 4.5 and RCP 8.5, and all the time series except at NT under RCP 8.5 where yield declined by −9.59% from the observed storage root yield data (Table 4).

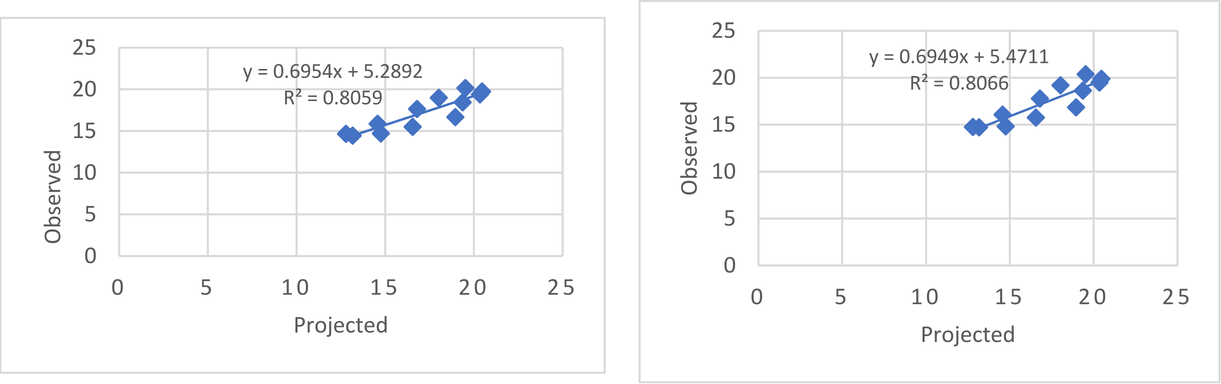
3.5. *Impacts of future climate on sweet potato performance*

The projected percentage (%) mean yield differences between baseline and simulated using RCP 8.5 and RCP 4.5 is presented in Table 5.

Good relationship was recorded between the baseline and simulated sweet potato fresh storage root yield under both RCPs for the time period NT, MT and ET respectively. Significant ($P < 0.05$) yield differences were observed between simulated and baseline yield data; sweet potato fresh storage root yield increased from baseline under both RCPs ranging between 33.1 and 39 t/ha in RCP 4.5 and

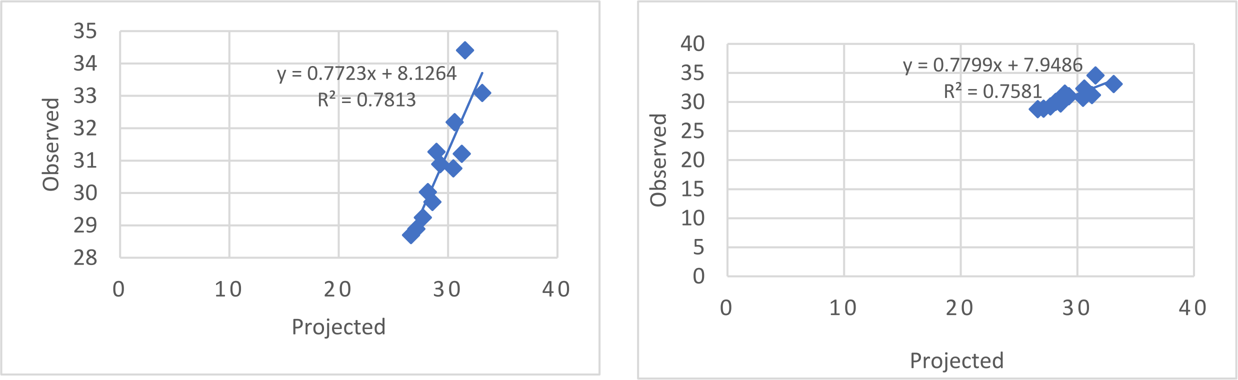
Table 2
Model valuation.

Parameters	Values
nRMSE	0.75
RMD	0.33
ME	0.98
R^2	0.82



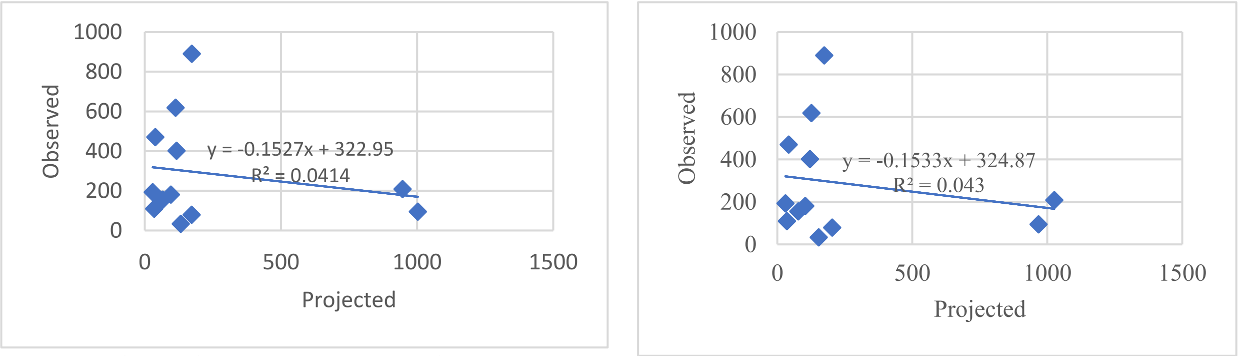
a: Relationship between baseline and simulated TMin RCP 4.5

b: Relationship between baseline and simulated TMin RCP 8.5



c: Relationship between baseline and simulated TMax RCP 4.5

d: Relationship between baseline and simulated TMax RCP 8.5



e: Relationship between baseline and simulated rainfall RCP 4.5

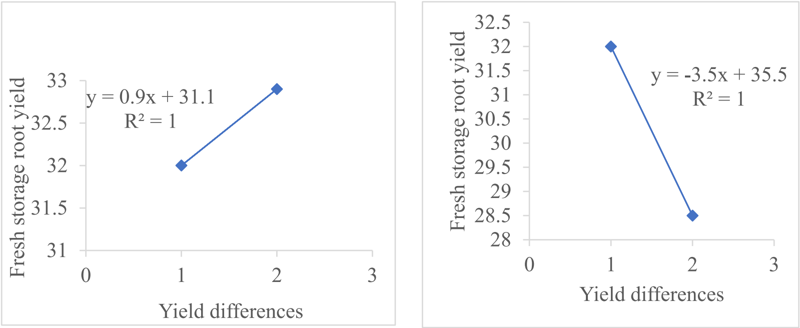
f: Relationship between baseline and simulated rainfall RCP 8.5

Fig. 1. Relationship between the baseline and the simulated rainfall and temperature data under RCP 8.5 and RCP 4.5. (a): Relationship between baseline and simulated TMin RCP 4.5. (*b*)*: Relationship between baseline and simulated TMin RCP 8.5. (c): Relationship between baseline and simulated TMax RCP 4.5. (d): Relationship between baseline and simulated TMax RCP 8.5. (e): Relationship between baseline and simulated rainfall RCP 4.5. (f): Relationship between baseline and simulated rainfall RCP 8.5.*

Table 3

Future trend in Temperature and Rainfall (%) difference from baseline data.

RCP	Period	TMax (°C)	Tmin (°C)	RF (%)
Baseline		29.81	16.39	383.6 mm/annum
4.5	Near-term (NT)	0.93	0.88	28.9
	Mid-term (MT)	1.79	1.75	36.1
	End-term (ET)	2.24	2.25	35.0
8.5	Near-term (NT)	0.97	1.05	30.2
	Mid-term (MT)	2.25	2.50	32.0
	End-term (ET)	4.10	4.54	37.8



a: Relationship between observed and projected yield using RCP 4.5

b: Relationship between observed and projected yield using RCP 8.5

Fig. 2. Relationship between the observed and projected storage root yield under RCP 8.5 and RCP 4.5. (**a): Relationship between observed and projected yield using RCP 4.5. (b): Relationship between observed and projected yield using RCP 8.5.**

Table 4

Percentage change in simulated fresh sweet potato storage root yield relative to the observed yield data over time (NT, MT and ET).

RCP	Period	Fresh storage root yield (t/ha)	% Change in fresh storage root yield
Observed		32.00	
4.5	Near-term	33.07	3.23
	Mid-term	33.30	3.90
	End-term	34.50	7.25
8.5	Near-term	29.20	−9.59
	Mid-term	34.00	5.88
	End-term	34.30	6.71

37.8–39.3 t/ha.

3.6. *Adaptation and mitigation strategies to maximise sweet potato production*

3.6.1. *Planting dates*

Yield simulation with different planting dates is presented in Table 6. Three unique planting dates termed as early (April 22), normal (July 01) and late (August 01) were used in the simulation of fresh storage root yield response using two RCPs (RCP 8.5 and

Table 5

Projected Sweet potato storage root yield deviation from the baseline under the two RCPs.

RCP	Period	Simulated mean yield (t/ha) against baseline mean yield
	Baseline	32.9
4.5	NT	33.1
	MT	34.7
	ET	35.9
8.5	NT	37.8
	MT	38.9
	ET	39.3
P-value		$P < 0.001$
Correlation coefficient		$R^2 = 0.046$

RCP 4.5), and different carbon dioxide concentrations. The simulated yield data shows that normal planting date has advantage over all other planting dates. The study observed significant yield increase from baseline ranging from 0.6% to 16.3% on normal planting date under both RCP 4.5 and 8.5 respectively. In the other hand, the study shows that significant yield loss between 52.3% and 108.2% is accrued under both RCPs when early planting is used, and a yield loss of about −12.7% at NT, RCP 8.5 when late planting date is preferred.

3.6.2. Maintain use of early maturing genotypes

Aba'ala is considered an arid agroclimatic zone of Ethiopia with limited crop growing cycles. Ininda genotype used in this study is early maturing with promising storage root yield (Table 4).

4. Discussions

The model minimised error between the observed yield and simulated yield as can be seen on the value of ME. Strong positive relationship coefficient, high ME and low nRMSE and RMD shows the aqua crop model sufficiency in accurate simulation of the studied parameters. According to Nash and Sutcliffe [34] (1970), ME range from ∞ to 1. The more nearer the model efficiency is to 1, the more accurate the model is. In this study, ME was 0.98 symbolizing a great accuracy in simulating sweet potato storage root yield. The observed yield data corresponds well with the projected yield data with less than 5% differences agrees with other authors [35] (2017) and [36] (2018). Strong positive correlations between the observed and projected temperature data show the ability of the model to correctly predict temperature meanwhile, the weak correlation between the observed and projected rainfall data may signify the weakness of the model to predict rainfall accurately. The projected increase in temperature observed in this study correspond with other authors [36,37]. End-term warming consequences in RCP 8.5 vary between 3.3 °C and 5.4 °C with an average of 4.5 °C. This is accompanied by high greenhouse gas emissions. Carbon dioxide gas emission is bound to increase at the end of ET (2070–2099) RCP 8.5 beyond 700 ppm [13,37]. Based on the projected increase in rainfall (37.8%) at the end-term period (2070–2099) under RCP 8.5, a combined increase in rainfall, and elevated CO_2 concentration augments sweet potato storage root yield production at ET under RCP 8.5 [13,15]. [38] (1998) observed 40% tuber yield increase in potato with carbon dioxide elevation of 660 μmol mol–1. Meanwhile, at ET under RCP 4.5, increase in temperature accompanied by a decrease in rainfall (−1.1%) from MT, shall negatively impact onto soil moisture availability by increasing evapotranspiration rate leading to decline in sweet potato storage root yield. Negative effects of increased temperature on potato tuber production outweighing the positive contribution of elevated CO_2 concentration were reported by some authors [15,36,39]. [40] (2021), in their study on impact of climate change on water requirements of directly sown sweetpotato in Kenya observed that in the time segment 2020–2039 (NT), the mean annual temperatures will rise by 36.3% and rainfall shall diminish by 16.7% which will shorten the length of sweet potato growing period by 42 days, increases sweet potato water requirement by 10.2% and lead to reduction in storage root yield.

The perfect correlation coefficient between the simulated and observed fresh storage root yield showed the ability of the aqua crop model to accurately mimic sweet potato yield. Varying planting dates give significant differences in sweet potato fresh storage root yield quantity. Comparatively low yield obtained from early planting date (April 22) could be due to very low soil moisture by the time of planting. Much as late planting date (August 01) gives a high storage root yield production, yet the normal planting date (July 01) had an advantage over them all. Highest yield was simulated at the end-term (2070–2099) where synchronization in temperature rise, precipitation increases and carbon dioxide elevation occurs leading to prolong sweet potato growth days, reduced transpiration rate, increased photosynthesis rate hence inevitable storage root yield enhancements. Hence normal planting date other than early or late planting could be a good insurance against climate change risks. This could be because of better synchronization of cropping cycle with the season. Other authors also reported that changing planting dates is the cheapest climate change adaptation strategy [23,36,41]. According to Adavi et al. [36] (2018), better potato yield was attained with late planting date. Conservation use of genotype with short gestation period shall enable the crop benefit from limited moisture during cropping season in an arid agroclimatic zone. Genotype Ininda used in this study had a short gestation period of between 90 and 100 days after planting [11]. According to Adavi et al. [36], use of early maturing genotypes with shorter growth duration is a good climate change adaptation strategy under changing climate.

5. Conclusions and recommendations

There was successful calibration and validation of FAO aqua crop model. The baseline and simulated TMax and TMin harmonized well though with a mild anomality in rainfall. The comparative high positive relationship between the experimental fresh sweet potato storage root yield data and the simulated yield data demonstrated that FAO aqua crop model is accurate in simulating sweet potato fresh storage root yield. Simulation results for sweet potato storage root yield comparatively shows that there shall be increased sweet potato storage root yield production under both RCP 4.5 and RCP 8.5 and the highest yield is obtained at ET (2070–2099) under RCP 8.5. Future climate has a positive impact on sweet potato storage root yield production under both RCP 8.5 and RCP 4.5: the elevated carbon dioxide concentration, percentage rainfall and temperature increase shall favor sweet potato storage root yield production. Maintaining early maturing genotypes and normal planting date (July 01) shall suffice for climate change risks of yield decline from the baseline. There is need to model yield under varying management practices including irrigation to ascertain their response. Similarly, there is a need to model the future impact of those important economic pests and diseases of sweet potato. Another study on the possibility of intercropping sweet potato as climate change risks insurance should be done.

Table 6

Simulated fresh storage root mean yield deviations from baseline and planting dates.

RCPs	Period	% Mean fresh sweet potato storage root yield difference from baseline and planting dates (Early, Normal, and Late)		
		Early	Normal	Late
	Baseline	15.6	32.9	31.83
4.5	NT	−67.0	0.6	3.7
	MT	−57.4	5.2	5.2
	ET	−53.7	8.4	4.6
8.5	NT	−108.2	14.9	−12.7
	MT	−52.3	15.4	3.2
	ET	−67.9	16.3	4.1
P- Value		0.025	0.007	0.019

Author contribution statement

G P L, Y T, A G: Conceived and designed the experiments; G P L: Performed the experiments; G P L, A G, D R: Analyzed and interpreted the data; G P L, A G, D R, Y T: Contributed reagents, materials, analysis tools or data and G P L Wrote the paper.

Data availability statement

Data will be made available on request

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

Thanks be to YHWH forever.

References

[1] V.R.K. Murthy, Basic Principles of Agricultural Meteorology (Pp. 4–4), BS Publications, 2002.

[2] IPCC (Intergovernmental Panel on Climate Change), Climate change 2014: synthesis report, in: Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Ipcc, 2014.

[3] IPCC, Summary for policymakers. In: climate change 2021: the physical science basis, in: V.P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, B. Zhou (Eds.), Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, In Press, 2021.

[4] IPCC, Climate Change: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.

[5] B. Gajanayake, K.R. Reddy, M.W. Shankle, R.A. Arancibia, A.O. Villordon, Quantifying storage root initiation, growth, and developmental responses of sweetpotato to early season temperature, Agron. J. 106 (5) (2014) 1795–1804.

[6] D. Wees, P. Seguin, J. Boisclair, Sweet potato production in a short-season area utilizing black plastic mulch: effects of cultivar, in-row plant spacing, and harvest date on yield parameters, Can. J. Plant Sci. 96 (2015) 139–147.

[7] F.P. Kawaye, M.F. Hutchinson, Maize, cassava, and sweet potato yield on monthly climate in Malawi, in: N. Oguge, D. Ayal, L. Adeleke, I. da Silva (Eds.), African Handbook of Climate Change Adaptation, Springer, Cham, 2021, https://doi.org/10.1007/978-3-030-45106-6_120.

[8] M. Fujiwara, C. Kubota, T. Kozai, K. Sakami, Air temperature effect on leaf development in vegetative propagation of sweetpotato single node cutting under artificial lighting, Sci. Hortic. 99 (3) (2004) 249–256.

[9] G. Dumbuyaa, H.A. Alemayehuc, M.M. Hasan, M. Matsunami, H. Shimono, Effect of soil temperature on growth and yield of sweet potato (Ipomoea batatas L.) under cool climate, J. Agric. Meteorol. 77 (2) (2021) 118–127.

[10] T. Tesfaye, T. Feyissa, A. Abraham, Survey and serological detection of sweet potato (Ipomoea batatas (L.) Lam) viruses in Ethiopia, J. Appl. Biosci. 41 (2011) 2746–2756.

[11] G.P. Lamaro, Y. Tsehaye, A. Girma, Orange-fleshed sweet potato [Ipomoea batatas (L.) Lam] genotype by environment interaction for yield and yield components and SPVD resistance under arid and semi-arid climate of northern Ethiopia, Ethiop. J. Sci.. Technol. 15 (3) (2022) 255–276, https://doi.org/10.4314/ejst.v15i3.3.

[12] IPCC (Intergovernmental Panel On Climate Change), Impacts, Adaptation and Vulnerability-Working Group II Contribution to IPCC Fourth Assessment Report, Cambridge University Press, London, 2007.

[13] J.M. Finnan, A. Donnelly, M.B. Jones, J.I. Burke, The effect of elevated levels of carbon dioxide on potato crops: a review, J. Crop Improv. 13 (1) (2005) 91–111.

[14] J.S. Amthor, R.S. Loomis, Integrating knowledge of crop responses to elevated CO2 and temperature with mechanistic simulation models: model components and research needs, in: G.W. Koch, H.A. Mooney (Eds.), Carbon Dioxide and Terrestrial Ecosystems, Academic Press, San Diego, CA, 1996, pp. 317–346. https://doi.org/10.1111/j.1365-3040.1991.tb01367.x.

[15] P.K. Biswas, D.R. Hileman, P.P. Ghosh, N.C. Bhattacharya, J.N. McCrimmon, Growth and yield responses of field-grown sweetpotato to elevated carbon dioxide, Crop Sci. 36 (5) (1996) 1234–1239, https://doi.org/10.2135/cropsci1996.0011183X003600050027x.

[16] G.B. Runion, S.A. Prior, T.A. Monday, J. Ryan-Bohac, Effects of elevated CO2 on growth of the industrial sweetpotato cultivar CX-1, Environ. Control Biol. 56 (2) (2018) 89–92, https://doi.org/10.2525/ecb.56.89.

[17] H. Poorter, Interspecific variation in the growth response of plants to elevated CO_2 concentration, Vegetation 104/105 (1993) 77–97, https://doi.org/10.1007/978-94-011-1797-5_6.

[18] S.A. Prior, G.B. Runion, H.H. Rogers, H.A. Torbert, D.W. Reeves, Elevated atmospheric CO effects on biomass production and soil carbon in conventional and conservation cropping systems, Global Change Biol. 11 (2005) 657–665, https://doi.org/10.1111/j.1365-2486.2005.00935.x.

[19] P. Jon, Agricultural development under a changing climate: opportunities and challenges for adaptation. Joint Departmental Discussion, in: Agriculture and Rural Development & Environment Departments vol. 1, The World Bank, 2009.

[20] G.M. Rimmington, D.A. Charles-Edwards, Mathematical Descriptions of Plant Growth and Development, 1987.

[21] FAO (Food and Agriculture Organization), Report on agro-ecological zones, in: Methodology and Results for Africa vol. 1, Italy, FAO: Rome, 1978.

[22] C. Sys, E. Van Ranst, J. Debaveye, Land Evaluation Part I: Principle in Land Evaluation and Crop Production Calculations, vol. 7, Agricultural Publications GADC, Brussels, Belgium, 1991, p. 280.

[23] Y.G. Beletse, R. Laurie, Du Plooy, C. P, S.M. Laurie, A. Van den Berg, Simulating the yield response of orange fleshed sweet potato'Isondlo'to water stress using the FAO AquaCrop model, II All Africa Hortic. Congr. 1007 (2013) 935–941.

[24] D. Raes, P. Steduto, T.C. Hsiao, E. Fereres, Reference Manual.AquaCrop 6.0, FAO, Rome, 2017. http://www.fao.org/nr/water/aquacrop.html. (Accessed 12 June 2019).

[25] Y.-P. Cen, R.F. Sage, The regulation of rubisco activity in response to variation in temperature and atmospheric CO2 partial pressure, Sweet Potato Plant Physiol. 139 (2005) 979–990.

[26] World soil information, SoilGrids: Autom. Syst. Global Soil Map. (2013). http://soilgrids1km.isric.org.

[27] L.P. Von Reeuwijk. Procedures for Soil Analysis, International Soil Reference and information Center, Wageningen, The Netherlands, 1993, pp. 56–62.

[28] E. Van Ranst, M. Verloo, A. Demeyer, M. Pauwels. Manual for the Soil Chemistry and Fertility Laboratory: AnalyticalMethodsfor Soils and Plants, Equipment and Management of Consumables, University of Ghent, Belgium, 1999, pp. 96–105. ISBN 90-76603-01-4.

[29] R Core Team., R foundation for statistical computing, in: 2021. R: A Language and Environment for Statistical Computing. R. Version 4.1.2, Austria, Vienna, 2021. http://www.r-project.org.

[30] H. Nicholas, Guide for running AgMIP climate scenario generation tools with R, AgMIP (2013). Available online: http://www.agmip.org/wp-content/uploads/2013/10/Guide-for-Running-AgMIPClimate-Scenario-Generation-with.

[31] R.A.I. Wilcke, L. Barring, Selecting regional climate scenarios for impact modelling studies, Environ. Model. Software 78 (2016) 191–201, https://doi.org/10.1016/j.envsoft.2016.01.002.

[32] Fao (Food and Agriculture Organization), ETo Calculator. Land and Digital Media Series No 36, FAO, Rome, Italy, 2012. http://www.fao.org/nr/water/ETo.html.

[33] K. Loague, R.E. Green, Statistical and graphical methods for evaluating solute transport models: overview and application, J. Contam. Hydrol. 7 (1991) 51–73.

[34] J.E. Nash, J.V. Sutcliffe, River flow forecasting through conceptual models. Part I: a discussion of principles, J. Hydrol. 10 (1970) 282–290.

[35] R. Raymundo, S. Asseng, R. Prassad, U. Kleinwechter, J. Concha, B. Condori, W. Bowen, J. Wolf, J.E. Olesen, Q. Dong, L. Zotarelli, M. Gastelo, A. Alva, M. Travasso, R. Quiroz, V. Arora, W. Graham, C. Porter, Performance of the SUBSTORpotato model across contrasting growing conditions, Field Crop. Res. 202 (2017) 57–76.

[36] Z. Adavi, R. Moradi, H.A. Saeidnejad, R.M. Tadayon, H. Mansouri, Assessment of potato response to climate change and adaptation strategies, Sci. Hortic. 228 (2018) 91–102.

[37] Climate Action Tracker, Governments Still Showing Little Sign of Acting on Climate Crisis, 2019. https://climateactiontracker.org/documents/698/CAT_2019-12-10_Briefing. (Accessed 11 November 2022).

[38] F. Miglietta, V. Magliulo, M. Bindi, L. Cerio, F.P. Vaccari, V. Loduca, A. Peressotti, Free air CO_2 enrichment of potato (*Solanum tuberosum* L.): development, growth and yield, Global Change Biol. 4 (1998) 163–172.

[39] R.J. Hijmans, The effect of climate change on global potato production, Am. J. Potato Res. 80 (2003) 271–280.

[40] C.W. Mbayaki, G.N. Karuku, Predicting impact of climate change on water requirements for directly sown rain-fed sweetpotato in the semi-arid Katumani region, Kenya, Trop. Subtropical AgroecoSyst. 24 (2) (2021) 61.

[41] R. Moradi, A. Koocheki, Nassiri, M. Mahallati, H. Mansoori, Adaptation strategies for maize cultivation under climate change in Iran: irrigation and planting date management, Mitig. Adapt. Strategies Glob. Change 18 (2013) 265–284, https://doi.org/10.1007/s11027-012-9410-6.